# БЕЗОПАСНОСТЬ ТЕХНОГЕННЫХ И ПРИРОДНЫХ СИСТЕМ

№4 2019

# SAFETY OF TECHNOGENIC AND NATURAL SYSTEMS

n.4 2019

ISSN 2541-9129

DOI 10.23947/2541-9129

Сетевой электронный теоретический и научно - практический журнал

Network Electronic Journal

http://bps-journal.ru/

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UDC614.8.086.2[62-49]:54-12
https://doi.org/10.23947/2541-9129-2019-4-2-8

# TO THE STUDY OF THE POSSIBILITY OF APPLICATION OF PERSPECTIVE SECURITY PROTECTORS FOR IMPROVEMENT OF LABOR PROTECTION AT WORK AT HEIGHT

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The article determines the relevance of the problem of rising injuries in the country. The article presents an algorithm for choosing the means of protecting workers from falling from a height. An innovative safety system for working at heights virtually eliminates the possibility of violating the rules of safety requirements, which can ensure human safety in a rapidly developing technogenic digital society.

**Keywords**: working conditions, protective equipment against human fall, technogenic digital society, hazard criteria, digital technologies

УДК614.8.086.2[62-49]:54-12
https://doi.org/10.23947/2541-9129-2019-4-2-8

# ИССЛЕДОВАНИЕ ВОЗМОЖНОСТИ ПРИМЕНЕНИЯ ПЕРСПЕКТИВНЫХ СРЕДСТВ ЗАЩИТЫ ПЕРСОНАЛА ДЛЯ СОВЕРШЕНСТВОВАНИЯ ОХРАНЫ ТРУДА ПРИ РАБОТЕ НА ВЫСОТЕ

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Рассматривается проблема роста травматизма в стране. Представлен алгоритм выбора средств защиты работников от падения с высоты. Предложенная авторами инновационная система безопасности работ на высоте практически исключает возможность нарушения соответствующих требований и может обеспечить безопасность человека в быстроразвивающемся техногенном обществе.

**Ключевые слова:** условия труда, защитные средства от падения человека, техногенное общество, критерии возникновения опасности, цифровые технологии.

**Introduction.** The priority of life and health of citizens is one of the defining directions of state policy. To ensure this thesis, the normative document "GOST R 54934-2012 Occupational safety and health management systems" is introduced in the Russian Federation. At the same time, statistics provide figures on the growth of occupational diseases of workers in various sectors of the economy. Studies have shown that the proportion of severe and fatal cases has not decreased in a quarter of a century, and the main causes are poor-quality and dangerous working conditions [1, 2]. The share of such cases in production with difficult working conditions in our country reaches 8 %, which is significantly higher than in developed countries. This situation testifies to the relevance of comprehensive study of injuries in production and planning of optimal measures and technical solutions that increase the safety of personnel [3].

**Technical solutions for injury prevention.** In modern conditions, scientific and technological progress and labor protection can be considered as a single vector that increases the efficiency of production while reducing and eliminating occupational diseases and injuries of workers. This is facilitated by the developments in the field of improving special high-altitude equipment. In the process of such devel-

opments, it is necessary to consider a multiple selection of technical proposals, inventions and patents presented in scientific and technical sources of the Federal Institute of industrial property (in the structure of Rospatent), as well as to classify them. In particular, this applies to equipment for the prevention of injuries of power engineers [4, 5].

The existing and currently being developed methods and devices to protect power engineers from injuries during high-rise works are differentiated according to Fig. 1. Such classification allows you to choose the most rational means of protection [4, 6].

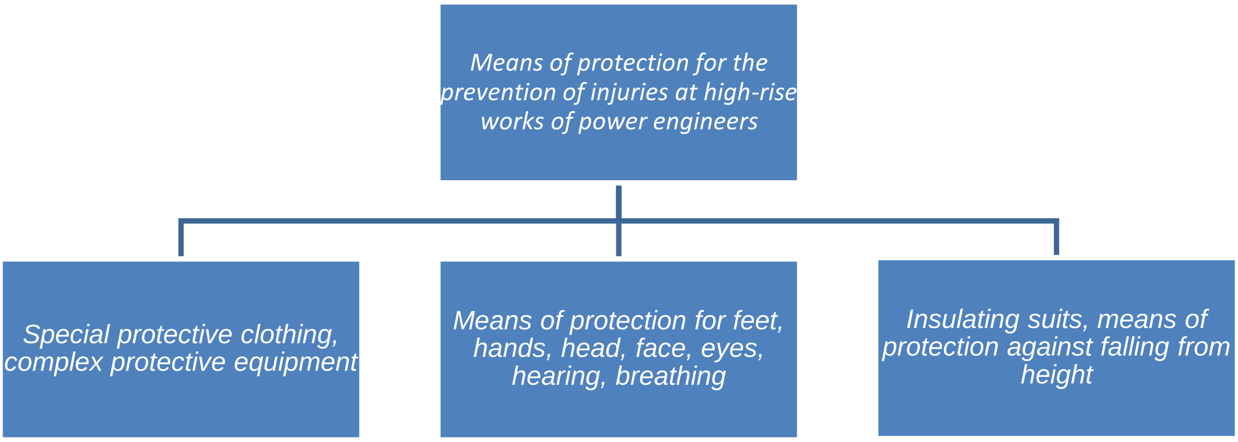


Fig. 1 Classification of technical solutions for injury prevention

In addition, the means of protection against falling from height can be classified according to the following characteristics:

- by the height of work performed;
- by the time of preparation of the protection to work;
- by the convenience of fastening of means of protection on clothes;
- by psychological comfort;
- by complexity of maintenance;
- by cost parameter.

**Parameters for assessing the protection of personnel performing work at high-rise facilities.** The following are the conditions and criteria for analyzing the quality of specific parameters, means and methods of personnel protection at high-rise facilities:

1. The height of the work ($j = 1$). This is actually the specified height of the possible use of individual personal protective equipment, stated by the manufacturer with technical parameters, characteristics and guarantees. The maximum estimate of this parameter $C_1 = 10$ points, the weight factor $b_1 = 10$.

2. The complexity of the industrial object ($j = 2$). This is the degree of dangerous proximity to the vertical planes of the facade of the building, architectural projections, external ventilation ducts, radio and television antennas, air conditioners. The maximum estimate of this parameter $C_2 = 10$, the weight factor $b_2 = 10$.

3. The time spent on the transfer of the protection from the storage state to the operational state. The maximum estimate of this parameter $C_3 = 10$, the weight factor $b_3 = 50$.

4. Convenience of placement of protection means: portable, easily moved, or stationary, noticeable against the background of other elements. In this case, the location on the overalls or the vertical surface of an industrial object is preferable compared to other considered methods, since work at height usu-

ally does not provide additional time for the preparation of the fixation points of equipment and rescue devices. The maximum estimate of the considered parameter $C_4$ = 10, the weight factor $b_4$ = 1.

5. Applicable type of electric power source. It can be a small portable source or a source of energy at an industrial facility for the operation of equipment and protective equipment. In this case, it is preferable to use free from the energy source means of protection. The maximum estimate of this parameter is $C_5$ = 10, the weight factor is $b_5$ = 10.

6. Participation of personnel (assistants, assistants of the master) in preparation for technical application and control of equipment integrity. The maximum estimate of this parameter $C_6$ = 10, the weight factor $b_6$ = 50.

7. Protection against intense heat. This includes the means (equipment, devices and elements) of protection against exposure to high temperatures, for example, in case of fire. The maximum estimate of this parameter $C_7$ = 10, the weight factor $b_7$ = 50.

8. Restrictions on weather conditions. It is preferable to be independent of weather conditions (wind, rain, snow) at the point of application. The maximum estimate of this parameter is $C_8$ = 10, the weight factor is $b_8$ = 1.

9. Emotional comfort during the operation of the protective equipment in difficult conditions. The maximum estimate of this parameter is $C_9$ = 10, the weight factor is $b_9$ = 10.

10. Operational availability, which means the possibility of using the means of protection by people of different ages and the level of technical qualification. This may be due to the difficulty of securing the device indoors and on the outside of a high-rise object. The maximum estimate of the given parameter $C_{10}$ = 10, the weight factor $b_{10}$ = 50.

11. The list of equipment by the number of structural elements, parts, assemblies required to equip protective equipment. The maximum estimate of this parameter is $C_{11}$ = 0, the weight factor is $b_{11}$ = 0.

12. Protection against unauthorized access, interference in the construction, breakage under the influence of various industrial and natural factors, vandal resistance, resistance to breakage when falling from heights allowed by the design. The maximum estimate of this parameter is $C_{12}$ = 10, $b_{12}$ = 1.

13. Interference functions for personnel. This is the quantity and level parameters of interference to employees of the enterprise, created by the protection means at all intervals of work performed. The maximum estimate of the given parameter $C_{13}$ = 10, the weight factor $b_{13}$ = 1.

14. Ease of operation of the fastening means of protection for industrial overcoat and equipment. The maximum estimate of this parameter is $C_{14}$ = 10, the weight factor is $b_{14}$ = 1.

15. Cost estimate of the means of protection. This is the approximate cost of a unit of protection, taking into account the production in specified volumes. The estimate of this parameter is taken $C_{15}$ = 0, the weight factor $b_{15}$ = 0. Parameter $b_{15}$ has an information orientation.

16. Scheduled maintenance. This parameter corresponds to the cost of all types of repair and maintenance for the planned period established by the manufacturer. The maximum estimate of the parameter $C_{16}$ = 0, the weight factor $b_{16}$ = 0 — information parameter.

**Expert assessment.** Means of protection against falling from height possess the individual technical features dictating the correct conditions of application. Table 1 shows the technical parameters $p_r^j$ of each means of protection of the *i-th* series. Technical parameters $p_r^j$ are quantified by experts for the whole range of *i-th* protection means. The definition of a set of important technical criteria becomes the

initial stage of comparative expert analysis. The values of each element of the obtained matrix consisting of expert estimates $a_r^j$ and estimates of the considered parameters $p_r^j$ are summed in each row of the *i*-th protection means. Here we take into account the above maximum estimates of this parameter $C_j$ of the considered technical characteristic and the values of their weight significance $b_j$ conditionally averaged for each of the characteristics in the studied interval of comparative expert analysis [5, 7].

The estimated calculations of the parameter $a_r^j$ in the first approximation, taking into account expert estimates, were carried out for all *i*-th means of protection either qualitatively, when the positive $a_r^j$ vector is 10 and the negative vector $a_r^j$ is 0, or by the formula for the weighted average:

$$a_r^j = 10\frac{(p_r^j - p_{\min}^j)}{(p_{\max}^j - p_{\min}^j)},$$

where $p_{\min}{}^j$ and $p_{\max}{}^j$ — the smallest and the largest value of matrix parameters $p_r^j$ from the number of the considered *j*-th characteristics around the *i*-th row of personnel protection means.

For the choice of means of protection against falling from height, the authors carried out the calculation of values of weight factors. If the interval among the main factors is relatively small (the factors do not differ from each other by more than 10 percent), it is possible to use a uniform linear scale. With a relatively large range of changes in the forming factors, the authors used a non-linear (logarithmic) scale.

The choice of means of protection of energy sector employees from falling from height was carried out by the method of optimization of technical parameters using a certain number of expert assessments of basic values. It is difficult to assess the technical parameters in the production process, as well as in the initial research, experimental and design development of the means of protection. With this choice, it is advisable to use a mathematical model, which can be used with several criteria for evaluating possible technical and design solutions. Such solutions take into account both quantitative characteristics (the height of the work, the time of preparation of the equipment for work) and qualitative measures (convenience of fastening the means of protection on the clothes of workers, comfort during operation, the need for maintenance) [6, 7].

The criteria for evaluating $A_i$ are pre-determined significant indicators, the specific values of which determine the assigned weight factors $k_i$. This dimensionless conditional form fits effectively into the computational procedures for expert matrices, and the evaluation of the target functions of $Ц_{ij}$ in the range from 0 to 10 points on the basis of experimental (expert) data has shown its effectiveness. In this technique, the degree of compliance with the optimal solution depends on the competence of the experts who set the parameters of the values $k_i$ and $Ц_{ij}$. The most accurate calculation is provided by the method of expert assessments involving several competent specialists. The scores of the target function are placed in the upper left corner of the matrix cells, and the product of the parameters $k_i$ and $Ц_{ij}$ -in the lower right. The values of the integral target functions $Ц_j$, obtained according to the adopted method for each solution variant, are in the bottom line.

Table 1 presents an example of the solution to the problem of choosing a means of protection of energy sector employees from injuries of a physical nature in difficult conditions, including falls from high-rise objects, by optimizing the parameters.

Table 1

The choice of individual means of protection of energy sector employees from injuries of a physical nature in difficult conditions

| Criterion for evaluation of protective equipment | Weight factor | Type of the system of individual protective equipment | | | |
|---|---|---|---|---|---|
| | | A Local shockproof devices, $n_1$ | B Protective equipment of electrically-insulating type, $n_2$ | C Protection from falling from height, $n_3$ | D Means of protection of respiratory organs, $n_4$ |
| Height of the operations | 0.1 | 4<br>0.4 | 4<br>0.4 | 5<br>0.5 | 3<br>0.3 |
| Time of preparation of means of protection | 0.2 | 3<br>0.6 | 4<br>0.8 | 8<br>1.6 | 5<br>1.0 |
| Operability of fastening of means of protection on clothes | 0.2 | 4<br>0.8 | 2<br>0.4 | 4<br>0.8 | 2<br>0.4 |
| Participation of assis-tants in the preparation of means of protection | 0.1 | 7<br>0.7 | 5<br>0.5 | 7<br>0.7 | 4<br>0.4 |
| Psychological comfort | 0.1 | 6<br>0.6 | 4<br>0.4 | 4<br>0.4 | 4<br>0.4 |
| Maintenance | 0.1 | 4<br>0.4 | 6<br>0.6 | 6<br>0.6 | 5<br>0.5 |
| Cost parameter | 0.2 | 3<br>0.6 | 4<br>0.8 | 4<br>0.8 | 3<br>0.6 |
| Target function $Ц_j$ | 1.0 | 4.1 | 3.9 | 5.4 | 3.6 |

**Special equipment.** Fall protection equipment ($n_1$) in the form of special equipment with a belt safety system is widely used to prevent injuries. The disadvantages of such means of the first generations are the complexity of interconnection and fixation of the belt safety system [5, 8, 9].

The proposed digital overall for work at height (Fig. 1) is a special clothing made of composite materials with reinforced zipper and safety belts, equipped with a special rope.

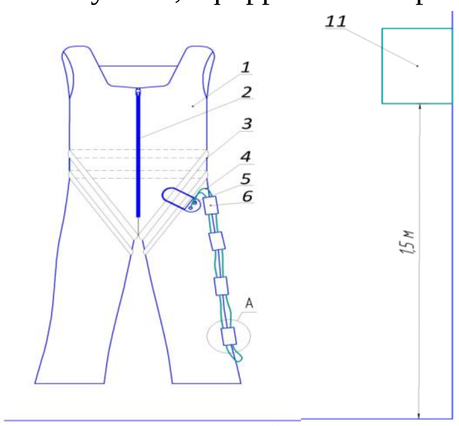


Figure. 1. Innovative overalls: 1 — special overalls; 2 — zipper; 3 — belt safety; 4 — power cable; 5 — digital carabiner; 6 — Velcro fasteners; 11 — control unit

The reinforced cable in the construction of the overall is made of carbon fiber, fiber and nylon. The use of fiber-optic wire together with the control unit in the digital carabiner, the transmitter of light signals-pulses and the receiver of signals-pulses provides constant control of the strength characteristics of the cable [9]. The digital altimeter built into the carabiner is set to a dangerous altitude. It gives the employee a reminding signal (buzzer) about the violation of security requirements and calls to the Central office at the same time. In addition to this information, the computer of the Central office records the periods of time when the employee is not fastened and fastened to the anchorages at a height [9].

The weight of the special protective equipment of the insulating type ($n_2$) shall ensure the possibility of safe working conditions of workers. Accessories attached to the material of the top of the protective equipment must not come into contact with the inner surface of the thermal insulation lining. The design of special equipment and hand protection equipment should allow the worker to perform all activities efficiently during routine or rescue operations. This equipment shall be used together with a fire helmet, personal respiratory and visual protection equipment, instruments, a radio station and personal protective equipment for the feet of the worker.

According to statistics, more than 560 fires are registered every day in our country, as a result of which about 40 people die every day and about 35 are injured [5, 7]. In case of fire, including electrical installations, a large amount of carbon monoxide, and other harmful and poisonous substances is released, and the oxygen concentration in the atmosphere is reduced to unacceptable values (about 17%). The most effective in such cases are the means of protection of respiratory organs (n4) of the insulating type, in contrast to the filtering means of protection; they allow evacuating with a local decrease in the concentration of oxygen in emergencies, since oxygen is released inside the insulating apparatus.

**Conclusion**. From the analysis of the obtained integral parameters, it follows that for the selected weight coefficients $k_i$, the means of protection against falling from height with the value of the target function $Ц_3$ = 5.4 are relevant for further study. This allows us to focus on more detailed studies of the elements of protection against falling from height and to begin the development of new anchor systems.

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UDC 331.45
https://doi.org/10.23947/2541-9129-2019-4-9-12

# LEAN PRODUCTION TECHNOLOGY AS AN ELEMENT OF THE PROFESSIONAL RISK MANAGEMENT SYSTEM OF THE ENTERPRISE

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The article describes the methods of production management, providing, in addition to improving productivity, the normalization of harmful and dangerous factors of the working environment. By results of comparison of the main indicators of individual professional risk of the worker the interrelation between improvement of working conditions and introduction of lean production in foundry is proved. The conclusion is made about the efficiency of lean production methods in terms of professional risk management.

**Keywords:** lean production, PRMS, individual professional risk

УДК 331.45
https://doi.org/10.23947/2541-9129-2019-4-9-12

# ТЕХНОЛОГИЯ БЕРЕЖЛИВОГО ПРОИЗВОДСТВА КАК ЭЛЕМЕНТ СИСТЕМЫ УПРАВЛЕНИЯ ПРОФЕССИОНАЛЬНЫМИ РИСКАМИ ПРЕДПРИЯТИЯ

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Описаны методы управления производством, обеспечивающие, помимо повышения производительности, нормализацию вредных и опасных факторов производственной среды. По результатам сравнения основных показателей индивидуального профессионального риска работника доказана взаимосвязь между улучшением условий труда и внедрением бережливого производства в литейном цехе. Сделан вывод об эффективности методов бережливого производства с точки зрения управления профессиональными рисками.

**Ключевые слова:** бережливое производство, СУПР, индивидуальный профессиональный риск.

**Introduction.** In recent years, the term "lean production" has become increasingly common in the Russian Federation, covering various types of economic activities. Initially, the Japanese company Toyota used the methods of lean production in the automotive industry, which subsequently gave it the opportunity to compete with American automakers. Based on the experience of Toyota, industrialized countries began to create their own concepts, applying them not only in the automotive industry, but also in trade and services.

The high competitiveness of enterprises using the methods of lean production is explained, first of all, by the economy of resources, which can be achieved by reducing or completely eliminating losses. Losses are any activity that does not bring value to the consumer. The creator of the technology of lean production, Taiichi Ohno, revealed three types of losses:

— múda — losses occurring in the production process (for example, due to unsatisfactory condition of the equipment, errors in calculations, etc.);

— múra — losses arising from the violation of the production schedule;

— múri — losses associated with the impact of unfavorable production environment on workers and equipment [1]. The exclusion of this type of losses is one of the main tools of professional risks management system (PRMS) of the enterprise. Thus, lean production and PRMS partly pursue the same goals. The task of the author of this article is to conduct a comparative analysis of the indicators of individual

occupational risk before and after the introduction of lean production methods in the foundry and find out how effective they are as an element of PRMS.

**Methods of lean production from the point of view of professional risk management.** To date, a huge number of methods of lean production have been developed, but most of them are aimed at increasing the value of products. From the position of professional riskology, the following may be the most effective:

— 5S system — keeping the workplace clean and tidy;

— TPM system (Total Productive Maintenance) — maintenance of equipment, ensuring product quality and compliance with safety requirements, elimination of harmful effects on workers;

— SMED system (Single Minute Exchange of Dies) — achievement of operational efficiency at replacement of tools of the equipment;

— Kaizen system — continuous improvement [2].

**Lean production implementation experience**. The methods of lean production described above have found their application at one of the machine-building enterprises of the Rostov region — OOO "PK "NEVZ", Novocherkassk. The technology Foscon, based on the use of cold-hardening mixture for molds and rods (Fig. 1) was introduced in the foundry, where there was an extremely unfavorable technogenic situation in 2011. To obtain a cold-hardening mixture, a safer SMAZOS mixer was introduced into operation.

The advantages of this technology and equipment were:

— minimization of emissions of harmful substances into the air of the working area;

— reduction of dust emission during transportation of materials and mold knockout;

— saving more than 50% of molding mixtures due to their re-application.

Fig. 1. Part of Foscon-process

The introduction of Foscon technology allowed them to achieve not only the improvement of working conditions in the foundry, but also the reduction of industrial injuries and occupational morbidity among workers. Thus, from 2005 to 2010, the labor protection service of OOO "PK "NEVZ" registered

22 accidents and 39 cases of occupational diseases, and from 2013 to 2018 — a total of 9 accidents and 6 cases of occupational diseases (table. 1-2) [3-6].

Table 1

Statistics on industrial injuries, professional morbidity in the foundry before the introduction of lean production (2005-2010)

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|
| Number of accidents | 7 | 5 | 3 | 2 | 3 | 2 |
| Number of professional diseases | - | 25 | 10 | 4 | - | - |

Table 2

Statistics on industrial injuries, professional morbidity in the foundry after the introduction of lean production (2013-2018)

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|
| Number of accidents | 4 | - | 2 | 2 | 1 | - |
| Number of professional diseases | 3 | 3 | - | - | - | - |

**The impact of lean production on occupational risk.** Work [7] analyzes the working conditions before and after the introduction of lean production methods according to the basic indicators of individual professional risk (Hf, NV, IEWC, IPR) on the example of foundry professional group. Fig. 2. shows the results of the analysis.

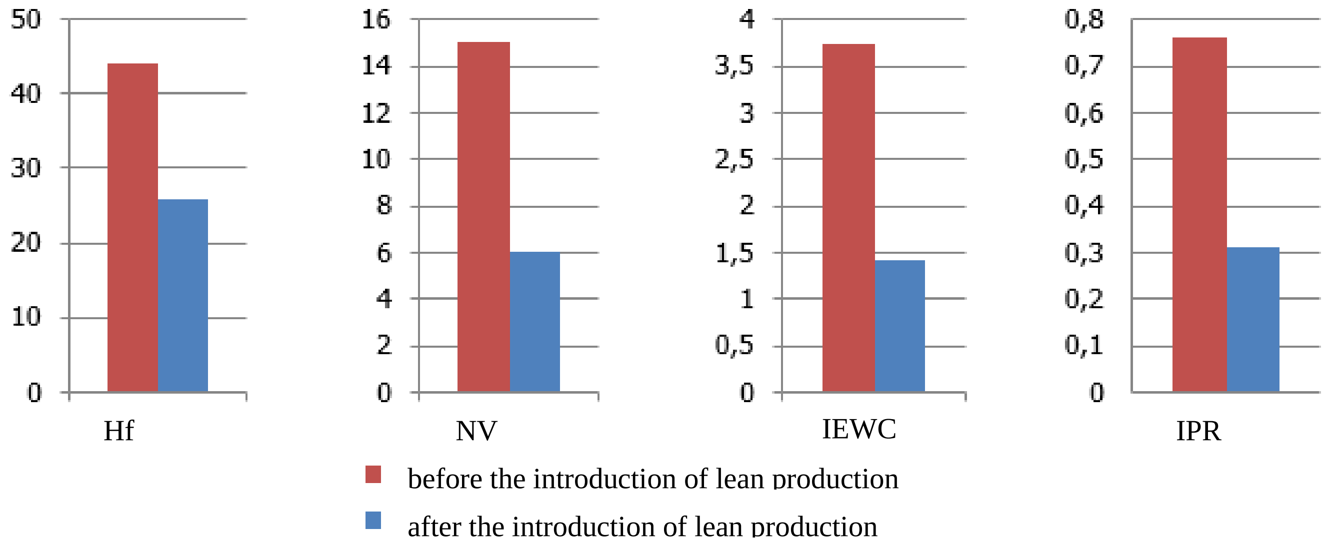


Fig. 2. Comparison of the main indicators of individual professional risk

**Conclusion.** Based on the comparative analysis of the main indicators of individual professional risk before and after the introduction of lean production methods in the foundry and data on industrial injury and occupational morbidity during this period, conclusions were made indicating the effectiveness of lean production methods as an element of the PRMS:

— the number of accidents decreased by 2.4 times, the number of cases of occupational diseases - by 6.5 times;

— the individual professional risk of the employee decreased by 2.5 times, the indicators of Hf, NV, IEWC — by 1.7, 2.5 and 2.7 times, respectively.

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UDC 62-781
https://doi.org/10.23947/2541-9129-2019-4-13-18

# MATHEMATICAL MODEL OF CONSTRUCTION OF THE COMPLEX INDEX OF SAFE OPERATION OF HOISTING MACHINES

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Application of modern methods of the theory of fuzzy sets and the theory of decision-making to a problem of construction of an integral index of safety in multicriteria spatio-textual signs on the basis of axiomatically entered concept of sufficiency is considered. The ways of constructing a complex index of safety in the production of lifting machines using computer algorithms that allow a qualitatively new level to solve the problem of processing a large amount of information necessary to improve the reliability of the estimates. The proposed method can be adapted for specific objects by expanding or changing the multi-criteria space of particular features that characterize the safety of operation of these objects in real conditions.

**Keywords:** safety, hoisting machine, integral indicator, private security metrics, sufficiency

УДК 62-781
https://doi.org/10.23947/2541-9129-2019-4-13-18

# МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ПОСТРОЕНИЯ КОМПЛЕКСНОГО ПОКАЗАТЕЛЯ БЕЗОПАСНОСТИ ЭКСПЛУАТАЦИИ ГРУЗОПОДЪЕМНЫХ МАШИН

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Рассматривается применение теорий нечетких множеств и принятия решений к построению интегрального показателя безопасности в многокритериальном пространстве частных признаков на основе аксиоматически вводимой концепции достаточности. Предложены пути построения комплексного показателя безопасности при грузоподъемных работах с использованием компьютерных алгоритмов, которые обрабатывают большое количество информации для повышения достоверности получаемых оценок. Метод может быть адаптирован для конкретных объектов путем трансформации многокритериального пространства частных признаков, характеризующих безопасность эксплуатации объектов в реальных условиях.

**Ключевые слова**: безопасность, грузоподъемная машина, интегральный показатель, частные показатели безопасности, достаточность.

**Introduction.** The analysis of safety of operation of hoisting machines shows that at the existing economic situation and the increasing requirements to maintenance of works, the measures applied now in the considered direction do not give satisfactory results. One of the ways to solve the problem is the use of automated systems that can facilitate and simplify the work of structures that ensure the safety of operation of hoisting machines. The need to create such systems was emphasized by the Board of Gosgortekhnadzor of Russia. At the same time, the developed systems should not only display the state of safety, but also contribute to the development of recommendations to improve its level at facilities. The authors propose to build an information-analytical algorithm for predicting possible emergencies at enterprises operating cranes, lifts and towers as an element of such system.

**Main directions of ensuring the safety of operation of hoisting machines.** The most important areas are:

supervision and control of equipment condition;

timely repair and maintenance of equipment;

training of specialists working with hoisting machines and control over their qualification level.

The analysis of the current state of problem solving in these areas shows the presence of significant shortcomings [1, 2], in particular, the lack of consistency and disparate solution of individual issues. The advantage of a systematic approach to ensuring the safety of the operation of hoisting machines is in the links between the main directions mentioned above, in contrast to the current situation, when all efforts to solve the problem are applied in isolation within each direction without taking into account their mutual influence. To implement the system approach, it is necessary to develop an integral (complex) indicator that can be used to predict the safety of operation of a particular object after a certain training, taking into account the concept of sufficiency set out below.

**The concept of sufficiency in ensuring the safety of facilities.** Problems of safety improvement can be solved by classical methods of optimization of known criteria. Usually, to assess safety an indicator is formed on the basis of supervision and control measures. However, with the help of a single indicator, it is difficult to justify decisions due to the difficulties of formulating a target functional that takes into account all factors affecting the safety of the object's operation. In this case, the problem becomes multi-criteria with a known set of solutions, among which it is necessary to find the best. Such problems are solved using modern decision-making theory [3].

The problem of improving safety with a complex of conflicting requirements imposed on objects, some of which can not be represented in the form of numerical indicators, is quite complex. In addition, in the case of multi-criteria safety assessment, the question of indicators (their number, significance, measurement methods, etc.) is debatable. Obviously, the set of criteria should cover all the essential aspects of the objects. The higher the indicator of the positive side of the safety of operation of the object and, accordingly, the lower the negative side, the better. However, this provision is not always true, and can be expanded by introducing the concept of sufficiency [4]. This concept assumes the existence of limits in safety indicators, exceeding which is meaningless, since it does not lead to a real result, and in some cases reduces the safety due to the presence of initially unaccounted factors (uncontrolled indicators).

From the mathematical point of view, the concept of sufficiency is that when certain conditions (sufficiency conditions) that determine the correctness of the statement $P$ are met, it becomes obviously true. Therefore, the concept of sufficiency in this case includes the formulation of conditions under which the statement that the object is operated safely becomes true. The set and formulation of sufficiency conditions depends on the specifics of the object, the conditions of its operation and the requirements imposed on it [4]. We assume that for each of the $m$ indicators characterizing the safety of the object operation, there is a given threshold value $d_i$. Then the excess of this value by the estimates $x_{i\nu}$ and $x_{i\mu}$ for the analyzed objects is a necessary and sufficient condition of equivalence from the point of view of the required level of safety:

$$a_\nu \sim a_\mu \Leftrightarrow x_i^\nu \geq d_i, \qquad x_i^\mu \geq d_i, \qquad i = 1, \dots, m.$$

This condition is a variant of the mathematical formulation of the concept of sufficiency, and the boundary $d_i$ introduced in this way will later be called the level of sufficiency for each of the indicators. Obviously, in practical terms, the key thing here is to determine the levels of sufficiency (indicators threshold values) on the basis of qualitative and quantitative analysis of the safety of operation of the object.

**Construction of an integral indicator in the criterion space.** In the case of multi-criteria safety assessment, an excessively large number of indicators reduces the effectiveness of monitoring, as complex (system) analysis of information becomes difficult. In this regard, it is advisable to aggregate the indicators, i.e. to build one integral indicator that adequately conveys all the required information about the initial set of criteria [5]. The problem of aggregation is solved by constructing a hierarchical structure of indicators. At each level of the hierarchy, the number of private indicators, as a rule, should not exceed 10. The formed integral indicator in this case will be flexible enough to be able to include (or exclude) an additional set of indicators without significantly changing its structure [6]. Here it is expedient to use the principle of generalized criterion, when a metrized multiplicative relation of linear order is given on a set of partial indices [5].

Let us have a set $A = \{a_1, a_2, \ldots, a_n\}$ of objects, the level of safety of operation of which must be evaluated in a multicriteria space $Re^m$, characterized by a set of partial indicators $K = (k_1, k_2, \ldots, k_m)$. The set of objects $A$ is displayed in the criterion space $Re^m$ as a set of points forming a matrix of estimates:

$$X = \|x_{ij}\|_{n,m},$$

where $x_{ij} = k_j(a_i)$ — assessment of safety of operation of the object $a_i$ on a scale of a private indicator $k_j$; $n$ — number of objects in the set $A$; $m$ — number of indicators (scales of estimates) in the set $K$, on which the relation of the metrized multiplicative linear order is set [5].

To take into account the introduced concept of sufficiency and uncertainty of tne number of indicators, we map the initial indicators $K = (k_1, k_2, \ldots, k_m)$ to the indicators $R = (r_1, r_2, \ldots, r_m)$ by forming special membership functions $y_{ij} = r_j(a_i)$:

$$y_{ij} = 0, \text{ if } x_{ij} \le g_j;$$
$$y_{ij} = f(x_{ij}, g_j, d_j), \text{ if } g_j \le x_{ij} \le d_j;$$
$$y_{ij} = 1, \text{ if } x_{ij} \ge d_j.$$

The function $f(x_{ij}, g_j, d_j)$ varies from 0 to 1.

This mapping allows us to introduce an integral exponent representing some function $Z$ of the formed fuzzy exponents $r_j$ and blurred (in the sense of L. A. Zadeh [7]) ratio $S$ on pairs of training objects specified as points on the $z$ axis. The position of points on the $z$ axis uniquely depends on the coefficient vector $B = (b_1, \ldots, b_m)$. This allows us to define the function $Z$ as a linear combination of estimates $y_{ij}$ with a vector of coefficients $B = (b_1, \ldots, b_m)$, called convolution coefficients [8, 9]:

$$Z = \sum_{j=1}^{m} b_j r_j, \qquad z_i = \sum_{j=1}^{m} b_j y_{ij}, \qquad i = \overline{1,n}.$$

The components of the convolution coefficient vector are subject to the condition [8]:

$$b_j \ge 0, \sum_{j=1}^{m} b_j = 1.$$

The main problem is to construct the relation $S$ and reasonably define the vector $B = (b_1, \ldots, b_m)$.

**The method of determining the convolution coefficients**. To determine the components of the vector $B = (b_1, \ldots, b_m)$, some finite set $P$ of so-called training objects must be given, the level of safety of operation of which is objectively known and can be estimated by a numerical indicator. This makes it possible to form a kind of objectively approximating existing training matrix of paired relationships between these objects [10]:

$$Q = \|q_{rk}\|_{p,p}.$$

The size of a square symmetric matrix $Q$ is determined by the number "$p$" of the training objects in question from the set $P$, and its $q_{rk}$ elements are the known squares of the distances between the $r$-$th$ and $k$-$th$ training objects on the security preference axis.

To construct the relation *S* on pairs of training objects, we define the square of the distance between the *r-th* and *k-th* training objects on the *z* axis by the formula:

$$s_{rk}(B) = (z_r - z_k)^2 = \left[\sum_{j=1}^{m} b_j \left(x_{rj} - x_{rj}\right)\right]^2 .$$

Then the observed structure of the relationships between training objects on the *z* axis with a fixed vector *B* is determined by a square symmetric matrix:

$$S(B) = \left\| s_{rk} \right\|_{p,p} .$$

The correspondence of the structure of relationships between training objects, specified by the matrix *Q*, and the structure of relationships observed on the axis of indicators *z*, determined by the matrix *S(B)*, is estimated using the functional:

$$J(B) = \sum_{r=1}^{p-1} \sum_{k=r+1}^{p} \left[ s_{rk}(B) - q_{rk} \right]^2 .$$

The function *Z**, defined by the vector *B**, for which the value of the functional *J(B*)* is minimal, is an integral (complex) indicator of safety of the object. The solution to the problem of extremization of the functional *J(B)* belongs to the class of problems of minimization of smooth functions on the simplex and is considered in detail in [8, 9]. Taking into account the introduced concept of sufficiency, the maximum possible value of the integral safety indicator is equal to one. This corresponds to the equality of the unit of all private safety indicators, included in the integral indicator, i.e. implementation of all necessary and sufficient conditions under which the operation of the object becomes absolutely safe. The degree of proximity of the integral indicator to the unit shows the level of complex implementation of safety requirements for all private indicators. This allows us to determine not only the current state of safety, but also to predict the behavior of the object in case of changes in individual private indicators, and to manage these indicators [11, 12].

**Example of construction of hierarchical structure of safety indicators of hoisting machines operation.** When constructing a hierarchical structure, the following can be attributed to the ordinal indicators of the top level:

supervision and control over the equipment condition;
repair and maintenance of hoisting machines;
training of specialists and control over the level of knowledge.

The following criteria should be specified for the construction of private security indicators at the second and subsequent levels of the hierarchy:

supervision and control over the technical condition of cranes, hoists and towers;
fast and timely repair of devices that ensure the safety of machines;
training of specialists of all areas related to the operation of hoisting equipment.

The approximate structure of indicators for the three levels of the hierarchy is shown in Fig. 1.

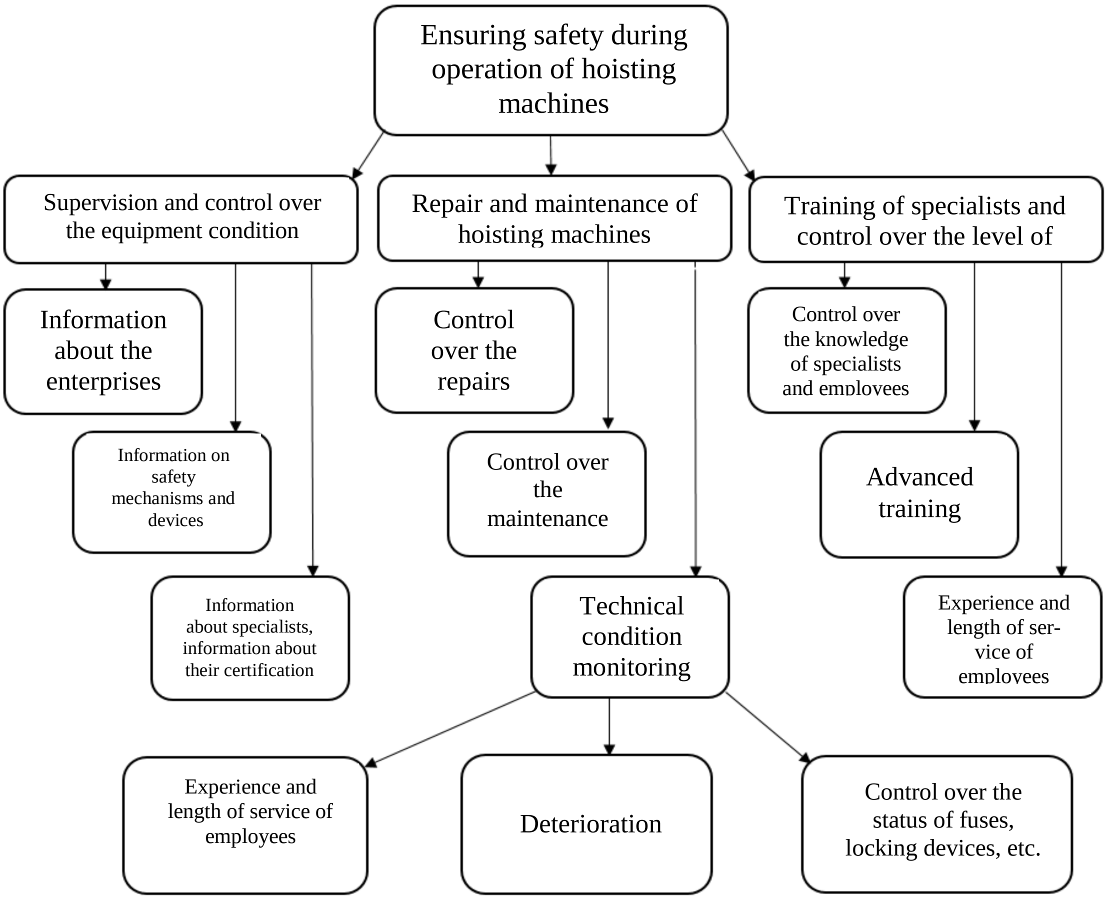


Fig. 1. Hierarchical structure of criteria for monitoring

**Conclusion.** The developed model for constructing a comprehensive indicator of safety of hoisting machines operation allows you to determine the level of current safety of the analyzed objects range from 0 (critical safety) to 1 (complete or absolute safety). The model is quite universal and can be used to assess the safety of other objects with appropriate changes in the hierarchical structure of safety indicators. In addition, the model allows you to automatically adapt the generated indicator to changing conditions by changing the training set of objects and conduct continuous monitoring of safety. To do this, it is necessary to monitor changes in the process of operation of private safety indicators at the lower levels of the hierarchical structure.

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UDC 621.86.065.3
https://doi.org/10.23947/2541-9129-2019-4-19-23

## ON THE TORSION OF TRACK CABLES OF JIG BACK ROPEWAYS

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Observations of the operation of jig back ropeways allowed us to suggest the presence of torsion of track cables of a closed structure under the influence of operational loads. In this case, the total weight of the cable and the car is a transverse load, and the cable itself is loaded with longitudinal resistance forces in its individual sections. The paper provides theoretical substantiation and experimental confirmation of the presence of torsional deformations of track cables of jig back ropeways under the influence of friction between the cable and the rocking saddles. A new method of rejection of such cables based on the control of torsional deformations is proposed.

**Keywords**: track cables, jig back ropeways, torsional deformations, method of rejection of cables, rocking saddles, rolling stock, safety margin, experimental studies of torsion, laser beam

УДК 621.86.065.3
https://doi.org/10.23947/2541-9129-2019-4-19-23

## О КРУЧЕНИИ НЕСУЩИХ КАНАТОВ МАЯТНИКОВЫХ КАНАТНЫХ ДОРОГ

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Наблюдения за эксплуатацией маятниковых пассажирских канатных дорог (МПКД) позволили авторам предположить наличие деформаций кручения несущих канатов закрытой конструкции при воздействии эксплуатационных нагрузок. При этом суммарный вес каната и вагона является поперечной нагрузкой, а сам канат нагружен продольными силами сопротивления на его отдельных участках. Выполнены теоретическое обоснование и экспериментальное подтверждение наличия деформаций кручения несущего каната МПКД под действием силы трения между канатом и башмаками линейных опор. Предложен новый способ отбраковки таких канатов, основанный на контроле деформаций кручения.

**Ключевые слова:** несущий канат, маятниковая пассажирская канатная дорога, крутильные деформации, способ отбраковки канатов, башмаки линейных опор, подвижный состав, запас прочности, экспериментальные исследования кручения, лазерный луч.

**Introduction.** In works [1-6] it is noted that during operation of jig back ropeways the track cable is subjected to tensile loads. At the same time, there are attempts to substantiate the presence of torsional deformations caused by the influence of the friction force from the slip of the cable on rocking saddle [7, 8].

**Theoretical justification of torsion of the jig back ropeways track cable.** According to Federal Norms and Rules [9, 10], the ratio of the minimum tension of the track cable $T$ to the weight of the loaded rolling stock $M_в$ of jig back ropeways must meet the following conditions:

for the cable with tensioner $\dfrac{T}{M_в} \geq 10$;

for the cable with anchored ends $\dfrac{T}{M_в} \geq 8$.

The friction force when moving the car on the rocking saddle can be determined by the formula:

$$P = cG_n + \mu g(g_0 + m_в)L + \varepsilon T, \quad (1)$$

where $G_n$ — the weight of the counterweight; $m_в$ — the mass of the car, per one meter of the track cable; $g_0$ — the mass of one meter of the cable; μ — the coefficient of sliding friction of the cable on the rocking saddle, μ = 0.2; $c$ — the loss factor on the stiffness of the track cable, c = 0.035; ε — the coefficient considering the angle of inclination of the track cable, ε = 0.17; $L$ — the length of the stretched section of the cable; $T$ — track cable tension; $g$ — acceleration of free fall.

The expression for the tension of jig back ropeways track cable has the form [2]:

$$T = G_n + 0{,}5 g_0 g l,$$

where $l$ — the length of the tension part of the cable.

The values of tensile stresses in the wires of the track cable are determined by the expressions presented in [3]:

- for the section of untwisting of the track cable on rocking saddle:

$$\sigma_p = E \cdot \left( \begin{array}{l} (G_n + \frac{P}{2}) \cdot \frac{1}{2A_{11}} \cdot \cos^2\alpha + \\ + \frac{A_{22} \cdot P}{A_{11} \cdot A_{22} - A_{12}^2} \cdot \cos^2\alpha - \\ - \frac{A_{12}}{A_{11} \cdot A_{22} - A_{12}^2} \cdot \frac{P}{2} \cdot r \cdot \sin\alpha\cos\alpha \end{array} \right); \quad (2)$$

- for the twisting section of the cable:

$$\sigma_p = E \cdot \left( \begin{array}{l} (G_n + \frac{P}{2}) \cdot \frac{1}{2A_{11}} \cdot \cos^2\alpha - \\ - \frac{A_{22} \cdot P}{A_{11} \cdot A_{22} - A_{12}^2} \cdot \cos^2\alpha + \\ + \frac{A_{12}}{A_{11} \cdot A_{22} - A_{12}^2} \cdot \frac{P}{2} \cdot r \cdot \sin\alpha\cos\alpha \end{array} \right), \quad (3)$$

where $E$ is the elasticity modulus; $r$ is the radius of lay of the layer of wires; α — the angle of lay; $A_{11}$, $A_{12}$, $A_{22}$ are the coefficients of stiffness of a track cable of a closed structure [11].

Substituting the value of the friction force, found by the formula (1), in the expressions (2) and (3), it is possible to determine the total stresses from stretching and torsion of the track cable in its sections of untwisting and twisting. For a closed structure cable at safety margins of 2.7 and 3.15 [9] tensile stresses depend on the ratio $\dfrac{P}{T}$. This ratio is taken in the range of 0.08 ... 0.2. Then the tensile stresses will be in the corresponding range of 90 ... 180 MPa. Such loading of the cable is accompanied by fatigue effect. Under these conditions, when the parameter $\dfrac{P}{T}$ reaches an abnormal value ($\dfrac{P}{T}$ > 0.2), the outer shaped wires may break and other defects may develop. This will reduce the service life of a jig back ropeway track cable of a closed structure beyond repair.

**Devices and methods of experiment.** To experimentally confirm the presence of torsion deformation of the jig back ropeway track cable there has been developed a device consisting of a movable and fixed brackets attached to the cable. A screen is mounted on a movable bracket, a laser ruler is mounted on a fixed one. The fixed bracket can be rotated together with the cable when torsional deformations develop. As a result, the angle of rotation of the beam is fixed on the screen of the movable bracket. The experimental study was conducted at jig back ropeway of the Research institute "Gorlesekol", Sochi. Below there are the parameters of this road:

length of the road — 1.1 km;
number of cars — 2;
number of wagon wheels — 8;
number of passengers in the car — 30;
weight of the car — 1.1 tons;
weight of the tension load — 44 tons.

To measure the torsion strain of the track cable, the device was fixed at a distance of 3 meters from the cable attachment at the drive station (Fig. 1).

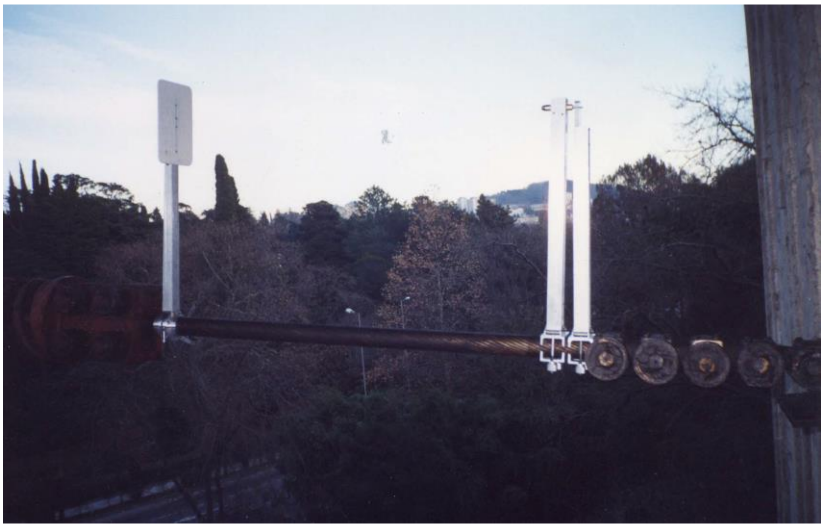

Fig. 1. General view of the device for measuring the torsion of the track cable of a closed structure

After adjusting the laser beam, a loaded car at revision speed moved in the direction of the drive station to the tension one. The deviation of the laser beam from the center of the screen ranged from 6° to 8° (Fig. 2). The measurement error of the relative torsion of the track cable did not exceed 7×10-3 mm$^{-1}$.

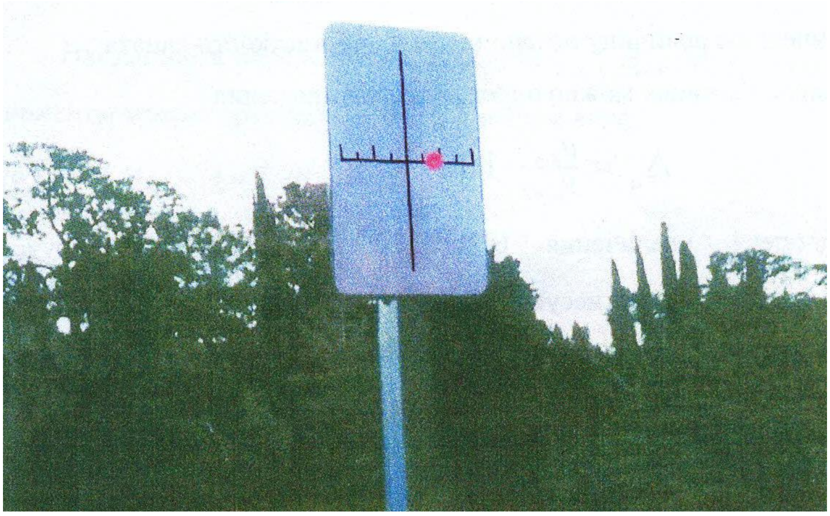

Fig. 2. Fixation of torsion of the track cable

**Analysis of research results.** The obtained results made it possible to propose a method for cables rejection based on the comparison of torsional deformations of their sections located near the place of fastening. During operation, the torsional rigidity of cables is reduced due to wear, corrosion, technological imperfections. The spread of mechanical properties, uneven tension of wires of both outer and inner layers contribute to an increase in torsional deformations. Therefore, periodical measurement of the torsion deformation of the cable can help you control the decrease in its strength.

In [8] the calculation of the relative torsion strain is presented as a complex of deformations caused by technological imperfections and friction of the track cable on the rocking saddle. Taking into account the requirements of Federal norms and rules about necessity of rejection of the track cable of a closed structure at the decrease of the area of cross-section of a wire by 10 % [9, 10], it is possible to write down the formula for rejection index on torsion:

$$\Delta_n = \frac{F_н}{F_u} \cdot 100\% = \frac{100\%}{0,9} = 111\% ,$$

where $F_н$ and $F_u$ — the cross-sectional area of the new and worn rope, respectively.

This means that if the torsional strain of the track cable of a closed structure exceeds 11%, it should be replaced.

**Conclusion.** The presence of torsion deformations of track cables of a closed structure due to friction between the cable and the rocking saddle of linear supports was justified theoretically and confirmed experimentally.

A method of rejection of jig back ropeways track cables, based on reducing the torsional stiffness of the worn cable in operation is proposed.

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UDC 678; 331.45
https://doi.org/10.23947/2541-9129-2019-4-24-31

# THE SOLUTION TO THE PROBLEM OF DISPOSAL OF USED TIRES, TAKING INTO ACCOUNT LABOR SAFETY IN A SMALL MOTOR TRANSPORT ENTERPRISE

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When organizing a site for the processing of used tires at a motor transport enterprise, a wide range of harmful and hazardous production factors leads to increased noise levels. The source of his education is a disintegrator. It was established that at the studied workplace the equivalent sound level is 88 dBA with a norm of not more than 80 dBA (for the 2nd class). Not only the operator, but also workers performing their labor functions nearby are exposed to noise in the study area. The solution to the problem of reducing noise exposure is associated with a preliminary calculation of acoustic screens, determining the necessary area of sound-absorbing material, fasteners, etc. The performed studies show the need to install 7 screens with a total area of 20 m$^2$ to satisfactorily reduce the sound level to the values regulated by sanitary and hygienic requirements. A decrease in the prevailing factor will entail a general decrease in the class of working conditions by hazard and hazard of the operator by one degree.

**Keywords:** tire recycling, grinding plant, disintegrator, chopper, working conditions, harmful and hazardous production factors, noise reduction.

УДК 678; 331.45
https://doi.org/10.23947/2541-9129-2019-4-24-31

# РЕШЕНИЕ ЗАДАЧИ УТИЛИЗАЦИИ ИЗНОШЕННЫХ ШИН С УЧЕТОМ БЕЗОПАСНОСТИ ТРУДА НА МАЛОМ АВТОТРАНСПОРТНОМ ПРЕДПРИЯТИИ

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На участке по переработке изношенных шин фиксируются различные вредные и опасные производственные факторы, в том числе повышенный уровень шума от дезинтегратора. Здесь эквивалентный уровень звука равен 88 дБА при норме не более 80 дБА (для 2-го класса). Причем воздействию шума подвергается не только оператор, но и сотрудники, работающие поблизости. Задача по снижению шумового воздействия может быть решена, если использовать акустические ширмы. Важно правильно рассчитать их необходимое количество, площадь шумопоглощающего материала и пр. Исследования показывают, что установка 7 ширм общей площадью 20 кв. м обеспечивает уровень шума, соответствующий санитарно-гигиеническим требованиям. Как следствие, может быть снижен класс условий труда по вредности и опасности.

**Ключевые слова:** переработка шин, установка по измельчению, дезинтегратор, измельчитель, условия труда, вредные и опасные производственные факторы, снижение шума.

**Introduction.** The activities of small road transport enterprises involve the generation of waste such as used engine oil, batteries, worn or damaged vehicle components and tires. The latter are extremely flammable. The burning temperature of tires is equal to the temperature of combustion of coal; harmful products, including carcinogens, are emitted into the air [1]. Tires are virtually biodegradable, and when stored and buried, serve as an ideal breeding ground for rodents and blood-sucking insects, vectors of infectious diseases. However, valuable raw materials can be extracted from tires: rubber, metal and textile cord. These materials do not change their original properties during operation.

Rational use of worn tires is of significant socio-economic importance. Transport enterprise "TransLogistikExpress" (Sarapul) solves the problem of reducing the volume of waste and involving

them in the resource cycle in order to reduce costs and form a careful attitude to the environment. This actualizes the development of technologies for recycling. A centralized tires collection system has not yet been established. In case of introduction of a physical method of their processing (cutting) in crumbs, the technological process will be accompanied by the raised levels of harmful influence (mainly vibroacoustic and chemical). When creating the technology of waste disposal at the transport enterprise "TransLogistikExpress", it is necessary to solve a number of problems, taking into account the requirements of labor safety.

1. To identify the main types of waste generated at the enterprise.
2. To analyze the quantitative composition and identify the dominant types of waste with the assessment of their impact on staff health.
3. To analyze the existing methods of processing and utilization of the main types of waste generated at the enterprise.
4. To develop technologies of utilization of used automobile tires taking into account safety of work of the operator on the disintegrator.

**Main part**

**Analysis of the existing methods of tire recycling and selection of a suitable option for implementation.** According to the survey of the owners of motor transport companies, about 40% of them use the services of waste disposal enterprises, 60% dispose of them in other ways, including on their own. Recycling of worn tires is a difficult technical task, which is further complicated by the use of metal cord.

Tires consist of rubber, which is made from natural and synthetic rubbers, and cord. Tire fabric can be made of polymer, textile and metal (metal cord) threads. The tire consists of a frame, cap plies, a tread, a bead and a lateral part. Fabric and polymer cord are used in passenger and light truck tires, metal cord - in trucks. Depending on the orientation of the cord threads in the frame, radial and diagonal tires are distinguished.

Car tires can be recycled in a variety of ways. One of the simplest is burning. In this case, there is a complete destruction of the initial products with the release of a significant amount of thermal energy. The energy potential of the tire is comparable to high-quality coal: its heat-carrying capacity is about 30 MJ/kg [2]. On the other hand, tires burning is accompanied by the formation of toxic substances, and the organization of an adequate cleaning system requires significant investment.

Another method is pyrolysis, that is, the chemical decomposition of rubber without access to oxygen. In this way, we get products for reuse in the petrochemical industry. Carbon black and other solids remaining after pyrolysis can be used as fillers. However, the organization of pyrolysis production (as well as any chemical production) requires significant resources and energy, which is not always advisable in a small enterprise.

The technology of tires grinding at moderate cutting speeds seems promising. In this case, we perform alternately: washing, beads cutting, pre-crushing, coarse crushing, fine crushing, separation and grinding. At the stage of preliminary crushing, a debeader, mechanical knives and a tire cutter are used, at the subsequent stages — crushing and grinding rollers, a separator for extracting metal particles and a vibrating screen. Currently, various types of equipment for rubber tires grinding are developed, which differ in the nature and speed of loading, the design of the working body, etc. For these purposes, abrasive belts and circles, guillotines, disc knives, presses, rollers, rotary knife crushers and other equipment are used. Domestic and foreign manufacturers develop technologies for worn tires crushing. For example, the company Cumberland (Germany) [3] produces high-performance plants for the processing of worn tires. Netmus companies (http://netmus.ru) and Polimech (https://polimech.ru/) are actively working in this direction on the Russian market. 1 ton of tires contains 600-650 kg of rubber, 130-150 kg of textile, 130-200 kg of metal. Waste tire is a valuable secondary raw material containing 65-70% rubber, 15-25% car-

bon black, 10-15% high-quality material. So, an acceptable option for tires processing in a small enterprise is the technology of mechanical grinding.

**Brief description of the technological process of mechanical grinding of tires and working conditions of the operator.** The disintegrator (shredder) produced by Tekhnoresursy [4] is shown in Fig. 1.

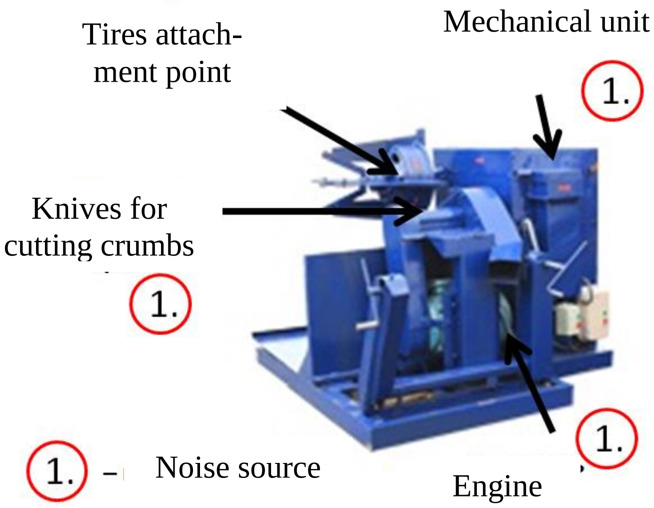


Fig. 1. Tire recycling plant

The equipment allows you to process all types of tires into crumbs. Its main characteristics:

— diameter of a landing ring of tires — from R15 to R33;
— outer diameter of tires — up to 2000 mm;
—weight of the tire — up to 600 kg;
— dimensions of the device (L×W×H) - 2200×2000×3000 mm;
-— weight of the device is not more than 1500 kg;
— cutting group — 10 milling cutters;
— service life of cutters — 180-350 tires (depending on the condition of the tire and its size);
— optimal performance of the machine-6-20 tires/h (up to 120 kg of rubber crumbs).

Up to 20 kg of clean rubber crumb (depending on the degree of tread wear) is removed from each worn truck tire with a diameter of up to 1200 mm. Next, the rubber-cord layer is removed, and the output is crumbs with pieces of cord, requiring additional cleaning. When processing large-sized tires with a diameter from 1600 to 2000 mm, it is possible to produce a clean crumb with small inclusions of textile fiber or metal wire weighing 60-150 kg. The productivity in the processing of large-sized tires is much higher than in the processing of standard truck tires of smaller sizes. In addition, the mechanical grinder has additional technical features to optimize the grinding process. As raw materials they used: used mine giant tires of "BelAZ", tractor, truck and off-road tires of various sizes with radial and diagonal construction of the cord.

When working on the installation, the operator performs the following actions:

1. Delivery of tires to the machine by rolling method.

2. Installation of the tire in the gripping drum manually (with a tire weight of 25-35 kg), installation of heavy tires using the lifting and landing mechanism.

3. Fixing the tire in the device by hydraulic latch mechanism.

4. Turning on the rotation drive of the latch mechanism and the beginning of the tire cutting — mechanical removal of the rubber layer at a fixed speed of rotation of the tire (more than 2000 rpm).

5. Adjusting the speed of supply of the cutting edge of the cutters to the tire in order to obtain a fraction of the rubber crumb of the required size, on which the productivity of the installation depends. It is higher in the production of large granules and decreases in the production of small fractions.

6. Then the clean rubber crumb is cut off before the appearance of the cord, and the second stage begins — the processing of the cord layers of the tire.

The management of the company "TransLogistikExpress" approved the following production parameters:

1) minimum area of the section — 25 sq. m;
2) number of operators per shift — 1 person;
3) electricity consumption — no more than 10 kW/h.

The finished products are stored in a metal foot container with a capacity of up to 30 thousand kg of crushed rubber. So, the production is divided into three areas: raw material storage area, crumb production sector, finished goods storage area.

**Characteristics of harmful and dangerous factors created by the work of the installation.** A specialist in labor protection at the enterprise notes that when working with a small-sizes grinding plant, harmful and dangerous production factors are recorded, shown in table 1.

Table 1

Actual state of working conditions

| Name of the production factor | Permissible level | Actual level | Excess |
|---|---|---|---|
| Noise:<br>equivalent sound level, dBA | 80 | 88 | 8 |
| Infrasound:<br>equivalent sound pressure level, dB Lin | 100 | 95 | – |
| General vibration:<br>equivalent level of vibration speed, dB on X/Y/Z axes | 92/92/92 | 70/68/73 | – |
| Local vibration:<br>equivalent level of vibration speed, dB on the X/Y/Z axes | 126/126/126 | 118/120/118 | – |
| Microclimate:<br>air temperature, ºC (category-Ib) | 21–23 | 22 | – |
| including air velocity, m/s | 0–0.2 | 0.2 | – |
| including humidity, % | 15–75 | 48 | – |

Noise, vibration, etc. occur due to the work of the cutting edges of the knives, the motor and the mechanical transmission (see Fig. 1). The general class of working conditions is the third, the second degree of danger.

The analysis of the table allows us to draw a conclusion that at work on installation the dominating negative factor is the raised noise level. General class of working conditions — 3.2. Practice shows that, as a rule, exceeding the noise level is a key aspect of the work of all types of small-sized plants, which implement cutting processes. These are drilling, turning and other machines.

**Measures to improve working conditions when working on the installation.** The level of noise in the workplace exceeds acceptable standards and should be reduced. Technical safety measures take precedence over organizational ones. Workers should be provided with personal hearing protection equipment.

The simplest method of noise suppression is the organization of obstacles to the propagation of sound from point A to point B. In practice, this is realized by the installation of noise screens. If the source emits sound in all directions, it is appropriate to manufacture a noise protective casing. On the one

hand, a logical solution may be the construction of a brick fence, but it is not always profitable. The conditions for placing such a fence in the general layout of the territory may not meet the requirements of ergonomics and rational use of available space. There is a need to build a portable or collapsible device. As a measure to improve working conditions at the workplace of the operator, it is proposed to establish a set of noise screens — corner and front screens (Fig. 2).

Fig. 2. Noise screen

The effectiveness of such devices depends on many factors, including the "impermeability" of the fence as a whole.

The corner screen is structurally two panels lined with foil acoustic felt enclosed in a metal frame. The screens are mounted on wheel supports, two of which are located on the inner side and equipped with a braking device. Thus, the bulk structure can move freely and be installed anywhere in the production area. The degree of protection of the cabin or room depends on the number of screens used. In the conditions of the enterprise "TransLogistikExpress" seven screens with a total area of 20 $m^2$ are needed.

The analysis of the market of noise-proof materials and designs showed that the best option in the conditions of work of the motor transport enterprise is application of acoustic felt with the foiled surface. This safe and eco-friendly solution improves vibroacoustic characteristics of passenger car interiors [5]. Thus, acoustic felt "HL Komfortmat" has the following characteristics: thickness 15 mm; size of one sheet 1500×1000 mm; specific gravity 0.7 $kg/m^2$; sound absorption coefficient 0.5 at a frequency of 1000 Hz [6]. Felt occupies one of the first positions among noise-absorbing materials. In addition, it is characterized by a low ability to form dust, resistance to high humidity, low weight, fire resistance, absence of abrasive materials in the composition, environmental friendliness.

According to preliminary estimates, the installation of a noise barrier in the form of screens is sufficient to ensure that the noise level meets the requirements for the class of working conditions 3.1 (82 dBA, with 80 dBA for the second class of harm and danger).

Fig. 3 shows the distribution of sound pressure levels at the operator's workplace.

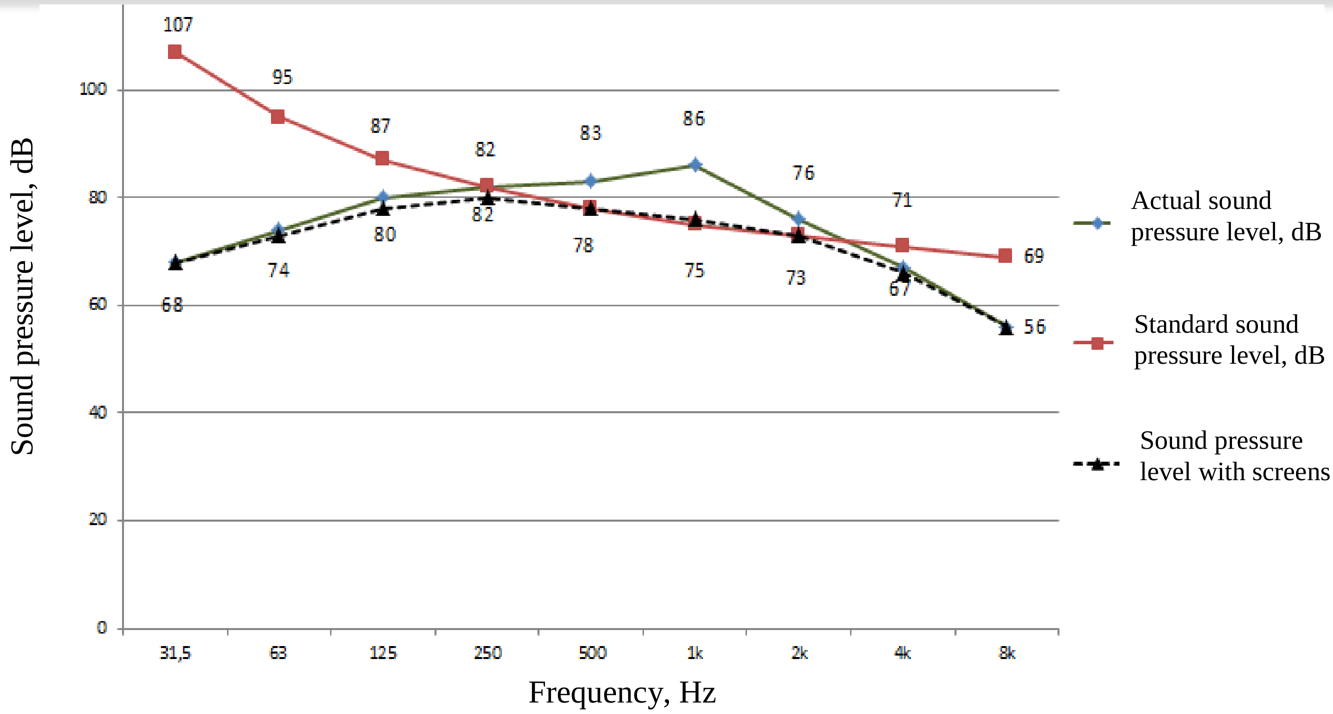


Fig. 3. Distribution of sound pressure levels at the operator's workplace

The initial data for plotting the normative values of the sound pressure level are given in [7]. The actual sound pressure level in the workplace is 88 dBA. The actual sound pressure level without the installation of the machine and the level of sound pressure achieved due to the noise screen during operation of the equipment are calculated according to the reference books [6, 8, 9]. The achieved level of sound insulation is calculated by the formula [8]:

$$\Delta L = 10\lg\frac{1+\dfrac{4r^2Q}{\Phi}\left(\dfrac{1}{A}-\dfrac{1}{S}\right)}{1+\dfrac{4r^2Q}{\Phi}\left(\dfrac{1}{A'}-\dfrac{1}{S}\right)},$$

where $\Phi$ — the source directivity factor; $r$ —the distance from the source to the calculated point, m; $Q$ — the spatial angle of radiation, steradian; $S$ — the area of sound absorbing material, m$^2$; $A$, $A'$ — the total and equivalent area of sound absorption, m$^2$; $\Delta L$ — the achieved level of sound insulation, dB.

It is possible to reasonably compare the real sound pressure level before and after the introduction of collective protection equipment only after the relevant activities. However, preliminary calculations show their feasibility and sufficiency.

**Conclusion.** Motor transport companies replace the used parts and components of vehicles and form production waste: tires with metal cord, tires with fabric cord, used metal car parts, batteries, cardboard air filters, used brake pads, and other types of waste. It is economically and ecologically expedient to recycle used tires (waste of hazard class IV), to involve them in the resource cycle. During the operation of the tire shredding plant on the production site, harmful factors, especially noise, begin to act (or worsen). The sound pressure distribution characteristics should be calculated at the design stage of such installations, which is not always possible. If the technological process is already established, the installation of collective protective means leads to the redistribution of sound levels in the room. Measurement of the actual sound level and its comparison with the maximum permissible values allow you to justify the

need for additional noise protection measures. With regard to the study conducted on the basis of calculations, it is assumed that the installation of noise screens in the circle around the machine for cutting used tires will reduce the actual sound level to indicators corresponding to class 3.1.

Further work in this direction involves the study of more large-scale industries for the processing of tires and improving the noise properties of acoustic screens by changing their design. As a result, the class of working conditions will be reduced to the second class.

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UDC 656
https://doi.org/10.23947/2541-9129-2019-4-32-38

# MEASURES TO OPTIMIZE ROAD TRAFFIC AND CALCULATIONS OF ENVIRONMENTAL SAFETY AT SOME PROBLEM SECTIONS OF ROAD-ON-DON ROAD INFRASTRUCTURE

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The article discusses the problem areas of the Combine Builders Square in Rostov-on-Don and possible measures that could improve traffic at this roundabout. Environmental indicators were calculated after carrying out the proposed measures to reduce CO emissions by cars. A comparative analysis of indicators before and after the events. The data obtained made it possible to establish how much the proposed measures to optimize traffic will help to reduce CO emissions by cars.

**Keywords:** car traffic, optimization of traffic, environmental safety, mass consumption of CO.

УДК 656
https://doi.org/10.23947/2541-9129-2019-4-32-38

# МЕРОПРИЯТИЯ ПО ОПТИМИЗАЦИИ ДОРОЖНОГО ДВИЖЕНИЯ И РАСЧЕТЫ ЭКОЛОГИЧЕСКОЙ БЕЗОПАСНОСТИ НА НЕКОТОРЫХ ПРОБЛЕМНЫХ УЧАСТКАХ ДОРОЖНОЙ ИНФРА СТРУКТУРЫ РОСТОВА-НА-ДОНУ

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В статье рассмотрены проблемные с точки зрения автомобильного трафика участки площади Комбайностроителей в Ростов-на-Дону и возможные мероприятия, которые могли бы улучшить ситуацию на этой развязке. Рассчитаны экологические показатели после проведения предложенных мероприятий по снижению выбросов CO автомобилями. Выполнен сравнительный анализ показателей до и после мероприятий. Полученные данные позволили установить, на сколько предложенные меры по оптимизации дорожного движения помогут снизить выбросы CO автомобилями.

**Ключевые слова:** автомобильный трафик, оптимизация дорожного движения, экологическая безопасность, массовый расход CO.

**Introduction.** The study of traffic on Kombaynostroiteley Square near the recreation center "Rostselmash" in Rostov-on-Don showed that the traffic flow at this interchange could be optimized.

There are three especially problematic areas in the specified territory:

— pedestrian crossing in front of traffic lights on Selmash Avenue, before entering the ring (Kombaynostroiteley Square);

— pedestrian crossing on Selivanova street after the exit from Kombaynostroiteley Square;

— the section from the exit from Kombaynostroiteley Square to Vilnyusskaya street (on the 1st Konnoy Armii) [1].

**Main part**

Measures to optimize road traffic in problem areas. The installation of traffic lights before entering the ring seems irrational. Traffic lights slow down traffic and create congestion on the roads. It is necessary to remove the traffic light and move the pedestrian crossing 50 m deep (towards the suburban bus station) [2]. Before the crossing, warning sign 5.19.1 "Pedestrian crossing" should be installed. Additional signs are not needed before the ring itself, since there are already signs: 2.4 "Give way" and 4.3 "Roundabout" [3].

It is also worth moving the pedestrian crossing 50 m deep on Selivanova street, further from the ring. At the entrance to Selivanova street from Kombaynostroiteley Square, drivers see sign 5.19.1 "Pedestrian crossing", which is less than 5 meters away from the roundabout. Because of this, vehicles stop to let pedestrians pass and form a traffic jam. With heavy traffic in rush hour, not less than 3-4 cars stop to let one pedestrian pass, which block two lanes on the ring area of Kombaynostroiteley Square. If the pedestrian crossing is moved deeper, the situation will change for the better, besides, all State standards and regulations will be observed [4].

Traffic on the 1st Konnoy Armii is one-way, two-lane. The lanes are wider than usual, so there is a possibility of trouble-free travel of three vehicles at once. However, a large number of cars are parked on both sides of the road, and this significantly reduces the capacity of the highway [5].

The traffic jam can start at this point, and end only after crossing on Vera Panova street. To improve the situation, it is necessary to prohibit parking from Kombaynostroiteley Square to Vilnyusskaya street (because after it the market parking begins). This section should be provided with signs: 5.27 "Parking restricted area"; 5.28 "End of Parking restricted area" and 8.5.4 "Duration" (7:00-19:00). This will significantly relieve the roadbed and increase the capacity of the road section [6].

**Environmental safety calculations.** Thanks to traffic optimization measures, traffic flow has increased from 10 km/h (2.78 m/s) to 20 km/h (5.56 m/s).

To determine the environmental impact of the activities carried out at the site under study, we compare the carbon monoxide (CO) emissions of passenger vehicles (V) with gasoline (forced ignition) and diesel engines. The calculation is carried out using methodological guidelines [7].

Mass flow rate, g/s, of the *i*-th pollutant (P) by a single vehicle (V) is determined by the formula:

$$M_i = Q_{\text{or}} c_i,$$

where $Q_{\text{or}}$ — the volume flow rate of exhaust gases (EG) of the engine of a single car, m$^3$/s; $c_i$ — the concentration of the *i*-th harmful substance in the exhaust gases of a single car, g/m$^3$.

Let us calculate the volume flow of exhaust gases by the formula:

$$Q_{\text{or}} = 0{,}0007\text{v}^2 - 0{,}0256\text{v} + 0{,}3184,$$

where $\text{v}$ is the average vehicle speed, m/s.

For passenger cars, it is determined by the formula:

$$\text{v} = 1{,}8665\text{v}_{\text{тп}},$$

where $\text{v}_{\text{тп}}$ is the speed of traffic flow, m/s.

Let us calculate the speed of passenger vehicles before and after the optimization of traffic on the intersection [8]. Before optimization:

$$\text{v} = 1{,}8665 \cdot 2{,}78 = 5{,}19 \text{ m/s};$$

after optimization:

$$\text{v} = 1{,}8665 \cdot 5{,}56 = 10{,}38 \text{ m/s}.$$

Volumetric flow rate of passenger vehicles exhaust gases in the traffic flow before traffic optimization:

$$Q_{\text{ог}} = 0,0007 \cdot 5,19^2 - 0,0256 \cdot 5,19 + 0,3184 = 0,204 \text{ m}^3\text{/s};$$

after optimization:

$$Q_{\text{ог}} = 0,0007 \cdot 10,38^2 - 0,0256 \cdot 10,38 + 0,3184 = 0,128 \text{ m}^3\text{/s}.$$

The concentration of CO in the exhaust gases of a car can be represented as an analytical dependence:

$$c_i = f(\bar{\alpha}),\ c_i = f(\bar{N}),$$

where $\bar{\alpha}$ — the relative coefficient of excess air; $\bar{N}$ — the relative power of the engine (table 1).

Table 1

Analytical dependences of CO concentration in exhaust gas on $\bar{\alpha}$

| Engine type | Range of variation $\bar{\alpha}$ | Concentration, $c_i$, g/m$^3$ |
|---|---|---|
| Petrol with forced ignition | 0–1,0 | $-237,71\bar{\alpha}^3 + 540,29\bar{\alpha}^2 - 385,24\bar{\alpha} + 92,937$ |
| With compression ignition | 0–1,0 | $5,6754\bar{N}^4 - 11,758\bar{N}^3 + 9,9078\bar{N}^2 - 3,5046\bar{N} + 0,7996$ |

The relative excess air ratio for passenger cars with gasoline (carburetor) engines is calculated by the formula:

$$\bar{\alpha} = 0,8775\bar{N}^3 - 2,1263\bar{N}^2 + 2,0224\bar{N} + 0,2387.$$

The relative power of the engine is determined from the equation:

$$\bar{N}N_{\text{ном}} = \frac{\left[k_{\text{ф}}\rho_{\text{в}}F_s v_j^2 + mg\cos\gamma\left(f \pm \text{tg}\gamma\right) \pm \delta_{\text{вр}}am\right]v_j}{\eta_{\text{тр}}}.$$

Here $\bar{N}N_{\text{ном}}$ — the product representing the effective engine power; $N_{\text{ном}}$ — engine rated brake power, W (for passenger gasoline vehicles we assume = 60 000 W; for diesel- = 70 000 W); $k_{\text{ф}}$ — wind shape coefficient (for passenger vehicles = 0.15); $\rho_{\text{в}}$ — - air density, $\rho_{\text{в}}$ = 1.293 kg/m$^3$; $F_s$ — frontal area of vehicle, m$^2$ (for passenger vehicles = 1.5 m$^2$); $m$ — mass of vehicle, kg (for vehicles we assume m = 1750 kg), $g$ — is the gravitational acceleration, m/s$^2$; $f$ — is the rolling resistance coefficient, $f$ = 0,02; $\delta_{\text{вр}}$ — the coefficient accounting for rotating mass; $a$ — vehicle acceleration, m/s; $\eta_{\text{тр}}$ — the mechanical efficiency of the transmission.

A minus sign in front of $\text{tg}\gamma$ is put when driving downhill. For the estimated calculation, we take $\gamma = 0$.

The product $\delta_{вр}$a for passenger vehicles can be represented by the expression:

$$\pm\delta_{\text{вр}}a = g\left(2,023v^{-1,0678} - \Psi\right).$$

here $\Psi$ — is the coefficient of reduced road resistance. Numerically it is possible to specify $\Psi = (f \pm \text{tg}\gamma)\cos\gamma$.

Before optimization:

$$\delta_{\text{вр}}a = 9,87 \cdot \left(2,023 \cdot 5,19^{-1,0678} - 0,02\right) = 3,243;$$

after optimization:

$$\delta_{\text{вр}}a = 9,87\cdot\left(2,023\cdot 10,38^{-1,0678} - 0,02\right) = 1,444\,.$$

Let us calculate the mechanical efficiency:

— for petrol engines with forced ignition

$$\eta_{\text{тр}} = -2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299\,;$$

— for compression ignition engines

$$\eta_{\text{тр}} = -1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755\,.$$

So, substituting all known values into the equation, we get $\bar{N}$ of a passenger gasoline (carburetor) car before optimization:

$$\bar{N} = \frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 5,19^2 + 1750\cdot 9,87\cdot 1\cdot 0,02 + 3,243\cdot 1750\right]\cdot 5,19}{60000(-2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299)}\,,$$

$$\bar{N} = \frac{0,5215}{-2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299}\,.$$

Hence:

$$-2,9224\bar{N}^4 + 3,4211\bar{N}^3 - 1,0995\bar{N}^2 + 1,0299\bar{N} - 0,5215 = 0\,.$$

This equation has two real roots ($\bar{N}_1$ = 0,959 and $\bar{N}_2$ = 0,536), one of which ($\bar{N}_1$) is approximately equal to one. Given the physical meaning of the problem, we assume that at given speeds the achievement of such a relative power is hardly possible and the most likely solution is the second real root ($\bar{N}_2$) [9]. Thus,

$$\bar{N} = \bar{N}_2 = 0,536.$$

After optimization:

$$\bar{N} = \frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 10,38^2 + 1750\cdot 9,87\cdot 1\cdot 0,02 + 1,444\cdot 1750\right]\cdot 10,38}{60000(-2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299)}\,,$$

$$\bar{N} = \frac{0,5024}{-2,9224\bar{N}^3 + 3,4211\bar{N}^2 - 1,0995\bar{N} + 1,0299}\,.$$

Hence:

$$-2,9224\bar{N}^4 + 3,4211\bar{N}^3 - 1,0995\bar{N}^2 + 1,0299\bar{N} - 0,5024 = 0\,.$$

The equation has two real roots ($\bar{N}_1$= 0,969 and $\bar{N}_2$= 0,517), one of which ($\bar{N}_1$) is approximately equal to one. Given the physical meaning of the problem, we assume $\bar{N} = \bar{N}_2$ = 0,517.

$\bar{N}$ of a passenger diesel car before optimization:

$$\bar{N} = \frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 5,19^2 + 1750\cdot 9,87\cdot 1\cdot 0,02 + 3,243\cdot 1750\right]\cdot 5,19}{70000(-1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755)}\,,$$

$$\bar{N} = \frac{0,447}{-1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755}\,.$$

Hence:

$$-1,3238\bar{N}^4 + 1,118\bar{N}^3 - 0,031\bar{N}^2 + 0,8755\bar{N} - 0,447 = 0\,.$$

The equation has two real roots ($\bar{N}_1$ = 1,11 and $\bar{N}_2$ = 0,461), one of which ($\bar{N}_1$) is approximately equal to one. Given the physical meaning of the problem, we assume $\bar{N} = \bar{N}_2$ = 0,461.

After optimization:

$$\bar{N}=\frac{\left[0,15\cdot 1,293\cdot 1,5\cdot 10,38^{2}+1750\cdot 9,87\cdot 1\cdot 0,02+1,444\cdot 1750\right]\cdot 10,38}{70000(-1,3238\bar{N}^{3}+1,118\bar{N}^{2}-0,031\bar{N}+0,8755)},$$

$$\bar{N}=\frac{0,4306}{-1,3238\bar{N}^{3}+1,118\bar{N}^{2}-0,031\bar{N}+0,8755}.$$

Hence:

$$-1,3238\bar{N}^{4}+1,118\bar{N}^{3}-0,031\bar{N}^{2}+0,8755\bar{N}-0,4306=0.$$

The equation has two real roots ($\bar{N}_1$ = 1,12 and $\bar{N}_2$ = 0,446), one of which ($\bar{N}_1$) is approximately equal to one. Given the physical meaning of the problem, we assume $\bar{N}=\bar{N}_2$ = 0,446.

Let us calculate the excess air ratio for a passenger vehicle with petrol engine.

Before optimization:

$$\bar{\alpha}=0,8775\cdot 0,536^{3}-2,1263\cdot 0,536^{2}+2,0224\cdot 0,536+0,2387=0,847.$$

After optimization:

$$\bar{\alpha}=0,8775\cdot 0,517^{3}-2,1263\cdot 0,517^{2}+2,0224\cdot 0,517+0,2387=0,837.$$

We determine the concentration of CO in the exhaust gases of passenger vehicle by the formulas from table. 1.

Passenger petrol (carburetor) vehicle before optimization:

$$c=-237,71\cdot 0,847^{3}+540,29\cdot 0,847^{2}-385,24\cdot 0,847+92,937=9,804\ \text{g/m}^3;$$

after optimization:

$$c=-237,71\cdot 0,837^{3}+540,29\cdot 0,837^{2}-385,24\cdot 0,837+92,937=9,614\ \text{g/m}^3.$$

Passenger diesel vehicle before optimization:

$$c=5,6754\cdot 0,461^{4}-11,758\cdot 0,461^{3}+9,9078\cdot 0,461^{2}-3,5046\cdot 0,461+0,7996=0,394\ \text{г/м}^3;$$

after optimization:

$$c=5,6754\cdot 0,446^{4}-11,758\cdot 0,446^{3}+9,9078\cdot 0,446^{2}-3,5046\cdot 0,446+0,7996=0,389\ \text{г/м}^3.$$

Based on the data obtained, we find the mass flow rate of a single passenger vehicle.

Gasoline carburetor car before optimization:

$$M=9,804\cdot 0,204=2,00002\ \text{g/s};$$

after optimization:

$$M=9,614\cdot 0,128=1,2306\ \text{g/s}.$$

Diesel vehicle before optimization:

$$M=0,394\cdot 0,204=0,0804\ \text{g/s};$$

after optimization:

$$M=0,389\cdot 0,128=0,0498\ \text{g/s}.$$

The mass consumption of CO by passenger cars in the traffic flow on the part of the road network is determined by the formula:

$$\sum M_{ijk}=M_{ijk}\lambda_{jk}K,$$

where $\lambda_{jk}$ — the share of cars by the purpose and type of fuel in the traffic flow (for gasoline passenger vehicles $\lambda_{jk}$ = 0,36, for diesel vehicles — $\lambda_{jk}$ = 0,014); $K$ — traffic volume (the number of vehicles on the road transport network at the moment), pcs.

The volume of traffic is calculated by the formula:

$$K = \left[ \frac{L - d_{\text{cp}}}{h} + 1 \right] z,$$

where $d_{\text{cp}}$ — the average length of the vehicle, m (we take 5.5 m for traffic flow); h — the average spatial interval between cars, m; z — the number of lanes (take z = 4).
Average space interval between cars:

$$h = 0,0285 v_{\text{т.п.}}{}^{2} + 0,504 v_{\text{т.п.}} + 5,7 .$$

Let us calculate the average spatial interval and the volume of movement (taking into account the increase in the length of the study area).

Before optimization:

$$h = 0,0285 \cdot 2,78^{2} + 0,504 \cdot 2,78 + 5,7 = 7,32 \text{ m;}$$

$$K = \left[ \frac{200 - 5,5}{7,32} + 1 \right] \cdot 4 = 110,3 \text{ pcs.;}$$

after optimization:

$$h = 0,0285 \cdot 5,56^{2} + 0,504 \cdot 5,56 + 5,7 = 9,38 \text{ m}$$

$$K = \left[ \frac{360 - 5,5}{9,38} + 1 \right] \cdot 4 = 155,2 \text{ pcs.}$$

Then the mass consumption of CO emissions by cars on the studied section of the road network before optimization is:

$$M = 110,3 \cdot \left( 2,00002 \cdot 0,36 + 0,0804 \cdot 0,014 \right) = 79,5412 \text{ g/s;}$$

after optimization:

$$M = 155,2 \cdot \left( 1,2306 \cdot 0,36 + 0,0498 \cdot 0,014 \right) = 68,8642 \text{ g/s.}$$

As a result of the optimization, the time of movement of passenger vehicles on the section has changed.

Before optimization:

$$t = \frac{200}{5,19} = 38,54 \text{ c;}$$

after optimization:

$$t = \frac{360}{10,38} = 34,68 \text{ c.}$$

Thus, the total emission by cars during the movement in the section before the optimization amounted to:

$$M = 79,5412 \cdot 38,54 = 3065,518 \text{ г} = 3,066 \text{ kg;}$$

after optimization:

$$M = 68,8642 \cdot 34,68 = 2388,21 \text{ г} = 2,388 \text{ kg.}$$

**Conclusion.** Thus, the implementation of measures to optimize the road traffic will reduce emissions from cars by about 22 %, which will lead to a significant improvement in the quality of atmospheric air in the study area [10].

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